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Green Manure for Restoring and Improving the Soil Nutrients Quality

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Abstract:

Decline in soil quality is considered as a major environmental concern globally. Production of good quality of food in an ample quantity for the growing population without deterioration soil quality and fertility is major challenge in present scenario. Use of agrochemicals to increase the productivity of soil is leading to loss of soil quality which also has significant impacts on human health and environment. Use of green manure to crop production was recognized as economically viable and environmentally acceptable approaches in substitution to the agrochemicals. Green manures are crops that were incorporate in agricultural field as a source of nutrient for succeeding crops. It also plays a vital role in restoring and improving the soil quality. There are numerous green manure plants in around the world which can contribute to improve soil biological, physical and chemical quality. It not only improves and restores the soil quality but also helps to manage agricultural diseases, pests and weeds.

Keywords

Green manure, soil fertility, organic matter, soil restoration, weed suppression

1. Introduction

Soil degradation which is characterized by decline in quality is considered as one of the major environmental concerns in the world [1]. This is also regard as a major constraint to achieving the required quality and quantity of agriculture production. As soil quality is defined as "the capacity of soil to interact with the ecosystem in order to support the biological productivity, the quality of other environmental components, thus promoting the health of plants and animals, including human beings "[2]. As soil is essential non-renewable resource which has potential of rapid degradation and extremely slow regeneration processes [3]. Reason behind the soil degradation are maximum usages of inappropriate agriculture technology such as intensive use of agro-chemicals [4], excessive tillage and continuous cropping system [5]. Other major degradation processes of agriculture soil are removal instantly shrinks the soil organic matter pool, depletion of the soil organic carbon (SOC) pool and loss in biodiversity, loss of soil fertility [6]. With the increased population pressure on the limited agricultural land for food, and other demand, farmers looks for alternative agricultural methods such as use of chemical fertilizer, pesticides and other chemical input in order to raise their productivity[7]. Continuous use of chemical fertilizers and pesticides to curb the problem of food deficit has been regarded as primary cause of soil degradation, health hazard and other environmental pollution [6,8]. Deterioration of the soil quality leads to loss in soil organic matter, soil erosion and depletion of nutrient flow and availability which ultimately have negative consequences to environmental as well as human health [9]. Trend of soil degradation can be reversed by and adopting of recommended management practices and conversing to a restorative land use [6]. Due to this reason, the application of organic amendment such as animal/farmyard manure, green manure, compost, vermicompost, biofertilizers, by product with high nutrient content etc. to the soils has become a common environment friendly practice for soil quality restoration, maintaining soil organic matter, reclaiming degraded soils as well as supplying the plant nutrients [10].

2. Green manure crops

Green manure is a specific species of plant, usually a legume, whether it is a tree, a bush, a vine, a crawling plant or algae, which is planted by farmers to maintain or improve their soil fertility or control weeds, even when they have many other reasons for growing these plants [11]. Green manuring is the process of incorporating green plants into the soil either by raising in same field or plants grown elsewhere at the green stage before flowering According to Pieters et al.[12], green manuring is the practice of enriching the soil by turning under fresh plant material either *in situ* or brought from a distance. Green manuring technology is economically viable, environmentally sustainable, and socially acceptable in sustainable agricultural systems [13]. A vast range of plant has potential as green manures. Green manuring crops can be plant of grain legume such as pigeon pea, green gram, soybean or ground nut; perennial woody multipurpose legumes trees viz., *Leucaena leucocephala* (Lam.) de Wit , *Gliricidia sepium* Kunth., *Cassia siamea* Lam. or non-grain legumes like sunn hemp (*Crotalaria spp*), dhaincha (*Sesbania spp*), *Centosemia*, *Stylosanthes* and *Desmodium* [13] . Among the hundreds of plant species, only a fraction of these have been well studies for their potential as green manure crops. Legumes crops are widely used in the agriculture in order to improve nitrogen content in the soil [14]**,** because of their potential to fix atmospheric nitrogen [15] through the symbiotic relationship between legumes and *Rhizobium* bacteria [16], the associations between plants and cyanobacteria [17]) as well as non-symbiotic association between free-living diazotrophs bacteria with the roots of the plant [18]**.** Particularly in organic farming system, symbiotic N fixation by legumes is an important source of N to agriculture [14].

3. Green manure for soil nutrient management

Green manure application to agriculture soil has been proven for increasing nutrient retention, nutrient-uptake efficiency, soil organic matter, microbial biomass, nutrient-uptake efficiency and reducing soil erosion nutrient [13, 15, 19-20]**.** But, influence of organic residues on soil properties depends upon the amount, type and size of the added organic materials [22]. Application of high-quality green manure such as legumes with low lignin and low C/N ratio could provide nutrient more efficiently by releasing nutrient quickly to plant [23-26]. Adequate supply of most limiting nutrient for plant growth N is regarded as a ‘keystone’ property for green manure use [27]. Slow release of nutrient from decomposition of green manure may provide better time to uptake nutrient by plant possibly increasing nutrient-uptake efficacy and crop production [23, 24]. During decomposition, initial phase may be attributed to the breakdown of water soluble organic matter such as starch and, cellulose, hemicellulose and amino acids, and the second slower phase possibly due to decomposition of lignin and other resistant material of the substrate [28].

Table 1: Review of green manure studies from 2001-2017.

Green manures	**Application rate**	**NPK content (kg ha^{-1})**	**Site**	**Reference**
Sunhemp (*Crotalaria juncea* L.)	0.9-2.9 t ha^{-1}(dry wt.)	23-82 kg N ha^{-1}	Zimbabwe	[29]
	10 t ha^{-1}(dry wt.)	NR	Indonesia	[30]
	11.1 t ha^{-1}(dry wt.)	195 kg N ha^{-1}	Cuba	[31]
	9 t ha^{-1}(dry wt.)	20.1 g N kg^{-1}, 5.4 g P kg^{-1}, 25.7g K kg^{-1}, 22 C:N	Brazil	[25]
Gliricidia sepium Kunth.	3 t ha^{-1}(dry wt.)	24 kg N ha^{-1}, 3 kg P ha^{-1}, 18 kg K ha^{-1}	Sri lanka	[32]
	15 t ha^{-1}(dry wt.)	0.86 % N, 2.33 % K	India	[33]
Glyricidia (*Glyricidia maculate* Kunth.)	5 t ha^{-1}(dry wt.)	4.13%N, 0.45%P, 1.85%K	India	[34]
Red clover (*Trifolium pretense L.*)	8.7 t ha^{-1}, fresh)	217 kg N ha^{-1}, 16 kg P ha,$^{-1,}$ C-3600	Sweden	[35]
	15 t ha^{-1}(dry wt.)^{1}	40.8 g N kg^{-1}, 358.9 g N kg^{-1} DM, 8.8 C:N	Spain	[9]
	12 kg ha^{-1} (seeding rate)	NR	Canada	[36]
Red clover (*Trifolium pratense* L.) + ryegrass (*Lolium perenne* L.),	NR	45.6%, 454 mg C g−1, 30.3 mg N g−1, 15 C:N	Denmark	[37]
Neem leaves (*Azadirachta indica* A.)	5 t ha^{-1}(dry wt.)	1.3 % N, 0.83% P, 1.67% K, 40% C, 30.7 C:N	Nigeria	[38]
	26.9 g pot^{-1}	1.66%N, 0.12%P, 1.49%K	Nigeria	
Pawpaw	5 t ha^{-}	1.4% N,	Nigeria	[38]

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leaves (Asimina trilob L.)	^{1}(dry wt.)	0.42%P, 1.51% K, 35 C, 25.0 C:N		
Moringa leaves (*Moringa oleifera* Lam.)	5 t ha^{-1}(dry wt.)	2.56% N, 0.43%P, 2.0%K, 36% C, 14.1 C:N	Nigeria	[38]
	14.4 g pot^{-1}	3.11%N, 0.38%P, 2.04%K, 0.52%Na	Nigeria	[39]
Mesquite leaves	5 t ha^{-1}(dry wt.)	2.67%N, 0.30%P, 1.82%K, 38% C, 17.7 C:N	Nigeria	[38]
Barley (*Hordeum vulgare* L.)	2.34-4.17 Mg ha^{-1}	104.2 kg N ha^{-1}	Italy	[40]
Common Vetch (*Vicia villosa* Roth.)	4.51-4.82 Mg ha^{-1}	187.0 kg N ha^{-1}	Italy	[40]
	27 -1 - 31 t ha^{-1}	NR	Turkey	[41]
	45 kg ha^{-1} (seedling rate)	NR	Canada	[41]
Sesbania aculeata	2.5 t ha^{-1}	40 kg N ha^{-1}, 8.7 kg P ha^{-1} , 19:1 C:N	India	[42]
	24 Mg ha^{-1}	116 kg N ha^{-1}	India	[43]
	24.5 - 34.8 t ha^{-1}	90.3 kg N ha^{-1}, 40.9 kg P ha^{-1}, 22.2 kg K ha^{-1}	Bangladesh	[44]
	3.73 g/kg soil	26.8, 375 g/kg C, 14 C:N	India	[45]
Sesbania rostrata Bremek. & Oberm.	10 t ha^{-1} (fresh)	3.79% N, 0.04%P, 0.90%K	India	[34]
Oat (*Avena sativa* L.)	60 kg ha^{-1} (seedling rate)	NR	Canada	[36]
	22500 kg hm^{-2}	NR	China	[46]
	10 t ha^{-1}	0.44 %K, 0.05 %P	Hawaii M.E.	[47]
Leucaena leucocephala Lam		51.6% C, 2.8%, N, 0.33%P	India	[48]

Sesbania bispinosa Jacq.	22500 kg	NR	China	[49]
Chinese milk vetch (*Astragalus sinicus* L.)	12.4 × 10^{3}- 49.7 × 10^{3} kg ha^{-1}	25.4 g N kg^{-1}	China	[50]
Chinese milk vetch (*Astragalus sinicus* L.)	60 kg ha^{-1} (seedling rate)	NR	Canada	[36]
Pea (*Pisum sativum* L.)	2.72-8.15 t ha^{-1}	31.76%C, 4.46%N, 0.61%P, 3.75%K, 54.91%OM , 7.12 C:N	Indonesia	[51]
T. diversifolia Hemsl.	4.3t ha^{-1} (DM)	3.10% N	Kenya	
T. diversifolia Hemsl.	17.1 g pot^{-1}	2.61%N, 0.47%P, 2.89%K, 0.63%Na	Nigeria	[39]
Huai bean (*Glycine ussuriensis* Regel & Maack)	2658 kg ha^{-1}	75.5 kg N ha^{-1}	Louthern Loess Plateau,	[52]
	2266 kg ha^{-1}	53.1 kg N ha^{-1}	Southern Loess Plateau,	[52]
Mung bean (*Phaseolus adiates* L.)	2371 kg ha^{-1}	59.2 kg N ha^{-1}	southern Loess Plateau,	[52]
Soyabean (*Glycine max* L.)	75 -150 kg ha^{-1}	44.8% C, 2.89%N,16 C:N	China	[53]
Soyabean (*Glycine max* L.) *Mucuna sp.*	13.4 t ha^{-1}	19g N kg^{-1}, 16.3 g P kg^{-1}, 3.0g K kg^{-1}, 19 C:N	Brazil	[25]
	1 , 1.5, 3, 6, 12, 24 t ha^{-1}	1.85-2 %N	Kenya	[26]
Mucuna sp. *Canavalia sp.*	8.1 t ha^{-1}	8.1g N kg^{-1}, 18.7g P kg^{-1}, 3.5g K kg^{-1}, 24 C:N	Brazil	[25]
	22500 kg hm^{-2}	NR	China	[46]
Ryegrass (*Lolium multiflorum* L.)	NR	0.04% N, 0.06% P, 0.20% K, 3.5% OM	India	[54]
Water Hyacinth	5 t ha^{-1} (Fresh)	3.15%N, 0.05%P,	India	[34]

		3.33%K		
Water Hyacinth *Erythrina indica* Lam.	10 t ha^{-1} (fresh)	3.2%N,0.47%P, 1.52%K, 18.8%C	India	[55]
	10 t ha^{-1} (fresh)	2.2 %N, 0.41%P, 1.37%K, 16.9% C		[55]
Alnus nepalensis D.Don	10 t ha^{-1} (fresh)	2.5%N, 0.40%P, 1.52%K,16.9% C	India	[55]
Parkia roxburghii G.Don	10 t ha^{-1} (fresh)	3.0%N, 0.43%P, 1.36%K,14.1% C	India	[55]
Acacia auriculiformis A.Cunn. ex Benth.	10 t ha^{-1} (fresh)	2,5%N, 0.39%P, 1.17%K,17.3% C	India	[55]
Cassia siamea Lam.	2.72-3.72 t ha^{-1}	78.3 kg N ha^{-1}, 24.7 kg P ha^{-1}, 11.4 kg K ha^{-1}	Bangladesh	[44]
Mimosa invisa Mart.	2.06-2.68 t ha^{-1}	931.7 kg N ha^{-1}, 17.5 kg P ha^{-1}, 9.68 kg K ha^{-1}	Bangladesh	[44]
Vigna radiata (L.) R.Wilczek	13.267 t ha^{-1}	8.5 g N kg^{-1}, 405.9 g N kg^{-1}, 47.7 C:N	Spain	[9]
Brassica napus L.	4.3 t ha^{-1}	2.3% N, 44% C	New Zealand	[56]
Lupin (*Lupinus angustifolius* L.)	15 t ha^{-1}	43% C, 3.6% N, 0.3% P	New Zealand	[57]

3.1. Physical properties of soil

As widely reported in various literatures, green manure applications improves the soil physical properties through increased in the stability and distribution of soil aggregates[58, 59], improved in water holding capacity[58, 59], increasing porosity and decreasing soil bulk density [60] decrease in volume of micropores while increasing macropores[58, 60]. Change in these properties may be the results of increases in organic matter in the soil through process of green manuring [62]. But, influence of the organic matter on soil physical properties depends on the quantity and type of organic materials added to the soil [63]. A significant decrease in bulk density and associated increase in total porosity of soil under green manure may be due to greater organic matter deposition and loosen of soil by its root action [60, 64]. According to the Sultani [58], green manuring crops, like *Sesbania* specif ically influence soil structural properties by producing of cementing agents from microbial activities and enmeshing soil primary particles and microaggregates into macroaggregation through direct physical action of roots. This may be the results of *Sesbania* deeper root system which helps to produce greater number macrospores [58].

3.3. Chemical properties

Green manure crops release nutrients during decomposition and consequently involve in recycling the nitrogen, phosphorus and potassium in integrated plant nutrients system [25, 46, 65–69]. Green manure either provides nutrient through biological nitrogen fixation legumes or through rapid decomposition and nutrient release from high nutritive non legumes crops [24, 25, 63, 70]. Green manure crops especially legumes are widely known to provide N to soils through biological N fixation, and this can increase the soil N supply to subsequent crops [71]. These green manures are capable of fixing atmospheric nitrogen with N-fixing bacteria associated at their roots [27].

Green manure amendments of the soil increased the organic matter contents of the salt-affected soil to many folds as well as enhanced the soil dynamics in terms of % organic carbon, % nitrogen, total carbohydrates and organo-minerals contents [72]. Higher availability of phosphorus from rock phosphate has been reported in rice due to green manuring [73]. Green manure can improve phosphorus uptake of succeeding crops by converting residual and unavailable native and fertilizer P to plant available form [73]. Amount of N release from green manure crops depends on the quality, quantity and timing of green manure applied to the soil [63]. Decomposition and nutrient release from green manure generally occur faster with lower C/N ratios, lignin and polyphenol contents [63]. These are the limiting factors of green manure that is integrated into soil. C/N ratio of plant materials used is considered an important parameter to predict dynamical patterns of the nutrient release and organic C mineralization rate [74].

3.2. Biological Properties

Various studies have shown inputs of green manure have been increase the size and activity of soil microbial communities [59, 68, 75-79]. 47 Years of field experiment was conducted to study the effect green manure amendment on soil biological properties. Research findings revealed that the number of fungi, bacteria and actinomycetes has been significantly higher in the field amendment with green manure when compare to the control. Green manure not only increases the biomass of soil microorganism, it also significantly increases the abundances of micro-arthropodes [80, 81].

Green manure amendments stimulate soil microbial growth, enzymatic activity, microbial biomass carbon and nitrogen with subsequent mineralization of plant nutrients [46, 57]. Organic matter decomposition and transformation of nutrients get enhances with the increases in soil microorganism and soil enzyme activities and consequently increased the efficacy of plant nutrient [82, 83]. Ye et al. [83] pointed out that green manure ryegrass (*Lolium multiflorum* L.) application increase soil microbial biomass carbon and nitrogen, soil respiration, the activity of soil urease, invertase, and catalase with contrast to the control treatment during 4 years of continuous experiment. --Soil microbial biomass-C was increased by 79.2% in the plots amended with green manures *Trifolium pratense* L. which was applied at the rate 25 tha^{-1} compared to the control soil Tejada et al.[9]. Increases in Microbial biomass C and N was also obtained by [48, 56, 68, 81, 84]**.** Increase in soil microbial biomass carbon and respiration can be due to the incorporation of easily decomposable organic materials, which stimulate the microbial activity [1].

4. Green Manure Crop Effects on Diseases Management

Green manures not only supply nutrient and organic matter to the soil it also reduces the disease caused by several pathogens. Most of green manure species can fix N with N-fixing bacteria and also have significant effects on disease development also [27]. It is very necessary to supply and manage nutrient availability which leads to change the environment of soil and that can control plant diseases in an integrated pest management. Similarly, Green manure can affects the availability of other nutrients such as N, P, K, Mn and Zn which can affects the tolerance of diseases [85].Various green manures have been reported in controlling the incidence of soil borne diseases by many researchers [86-91]. Applications of green manures of Sudangrass, winter pea, and broccoli at different biomass rates have reduced density of *Verticillium. dahliae* and severity of wilt [77]. Plant belonging to family Brassicaceae have been often used to control various plant pathogen such as *Rhizoctonia solani*, *Phytophthora erythroseptica*, *Pythium ultimum*, *Sclerotinia sclerotiorum*, and *Fusarium sambucinam* [89] Crops from Brassicaceae family generally associated with mechanism of biofumigation in which they produce glucosinolates that break down to produce isothiocyanates, which are volatile toxins to the various plant pathogen [92, 93]. Isothiocyanates is the chemical compound similar to methyl isothiocyanate, the active synthetic fumigant metam sodium [93]. Incorporation of green manure plants into soil release this compound through active hydrolysis process [92].

Diseases	Green manures	Study
Stem canker, black scurf, common scab, and silver scurf	*Brassica napus L.*	[91]
Pythium ultimum	Red clover (*Trifolium pratenseL.*)	[87]
	Rapistrum rugosum All. and *Cleome hassleriana* L.	[88]
	Avena sativa L., *Lolium multiflorum* Lam., *Hordeum Vulgare L.*, *Brassica napus L.*, *Brassica rapa L.*, *Raphanus sativa L.* , *Sinapis alba*, *Brassica juncea L.*	[89]
S. minor sclerotia	Broccoli (*Brassica oleracea L.*)	[94] [77]
Stem rot (*Sclerotinia sclerotiorum)*	*Brassica napus L.*, *Brassica juncea L. and Brassica campestris L.*	[95]
	Avena sativa L., *Lolium multiflorum* Lam., *Hordeum Vulgare L.*, *Brassica napus L.*, *Brassica rapa L.*, *Raphanus sativa L.* , *Sinapis alba*, *Brassica juncea L.*	[89]
	Sudan grass (*Sorghum*	[77]

	vulgare)	
	Crotalaria juncea L.	[96] [97]
Rotylenchulus reniformis	Pigeon pea (*Cajanus cajan*)	[97]
	Brassica napus L.,	[96]
	Tagetes erecta L.	[96]
	C. paulina	[23]
P. zeae, P. brachyurus	*C. ochroleuca* G. Don	[23]
	C. agatiflora Schweinf. ex Engl.	[23]
M. incognita,	*Crotalaria juncea L.*	[27]
	Fumaria parviflora Lam (Fumariaceae)	[99]
	Gliricidia maculata Kunth, *Thespesia populnea L.,* ***Calotropis gigantia*** **Linn.** *Azadiracta indica A.* ***Glycosmis pentaphylla*** Retz.	[100]
	C. agatiflora Schweinf. ex Engl.	[23]
M. javanica	*C. ochroleuca* G. Don.	[23]
Meloidogyne spp.	*Brassica napus L.*	[101]
Meloidogyne chitwood	*Avena sativa L., Lolium multiflorum* Lam., *Hordeum Vulgare L., Brassica napus L., Brassica rapa L., Raphanus sativa L. , Sinapis alba,*	[89]

	Brassica juncea L.	
Rhizoctonia solani	*Avena sativa L., Lolium multiflorum* Lam., *Hordeum Vulgare L., Brassica napus L., Brassica rapa L., Raphanus sativa L. , Sinapis alba, Brassica juncea L.*	[89]
Phytophthora erythroseptica,	*Avena sativa L., Lolium multiflorum* Lam., *Hordeum Vulgare L., Brassica napus L., Brassica rapa L., Raphanus sativa L. , Sinapis alba, Brassica juncea L.*	[89]
Fusarium sambucinam L.		

5. Green manure on weed suppression

Various green manure crops have been used for suppression of weed in agriculture system. Green manure eliminate the weed through its allelopathic effects, blocking light through surface cover, restricting growth and development by competing on space, water and nutrition [103-105]. Green manuring enriches diversity of the rotation and reduces the opportunities for weeds to become adapted to a particular cropping pattern. The important green manure crops include canola, rape seed, cereal rye, crimson clover, wheat, red clover, brown mustard, oats, cowpea, fodder radish, annual ryegrass, mustards, buckwheat, hairy vetch, and black mustard [106].

Green manures that secrete allelopathic chemicals into the soil that inhibit germination, growth and development of weeds present in the soil seed bank [107]. The extent of allelochemical release in the soil and the associated weed suppression depends on the quantity and quality, management practice as well as environmental conditions including the soil physical, chemical, and biological characteristics [104]. Field experiments conducted by (Haramoto and Gallandt,

2005) found reduce in subsequent weed biomass in the field incorporated by brassica cover crops, including canola, rapeseed, and yellow mustard The brassica species exclude alleochemical named glucosinolates which get decomposed into several compounds in natural environment. Isothiocyanates decomposed from glucosinolates are most important biological active compound which the germination and growth of exposed plants [109]. The complete ground cover due higher initial growth rates for height and leaf area development which to develop close dense canopy faster than weeds is one important quality of green manure [108].

6. Conclusion

Green manure can represent the sustainable tools for to improve soil fertility in intensive agriculture. Green manure has multiple effects on crop performance as well as soil management. Understanding the relative importance of green manure and use it as a part of cropping system might be able to applicable for soil rehabilitation and reclamation of land. On other hand, it restored the soil fertility, suppressed weed, and reduced soil borne diseases without any negative impacts to our ecosystem. Green manuring based cropping system may be alternatives to current and traditional crop production approaches. The use of green manure crops may not be economically viable without the provision of its multiple services such as nutrient supply, weed, diseases and pest management at a glance. Therefore, more research should be carried to developed new technology on the use of green manure as soil supplements.

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